A. Project Information
Final Report
Contract 12-0362-SA

Evaluation of N Uptake and Water Use of Leafy Greens Grown in High-Density 80-inch Bed Plantings and Demonstration of Best Management Practices

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B. OBJECTIVES

1. Document the quantity and pattern of N uptake pattern over the life cycle of baby lettuce, cilantro, spring mix (e.g. mizuna) and spinach
2. Evaluate quantities of irrigation water applied to these crops over the course of the growth cycle
3. Evaluate the rooting depth of the crops over the growing season
4. Evaluate fertilizer additives such as urease and nitrification inhibitors with pre/at-planting fertilizer applications to improve N use efficiency

C. ABSTRACT

These evaluations provided basic agronomic evaluations of vegetable crops grown on high-density, 80-inch wide beds: baby lettuce, cilantro, mizuna and spinach. The crops comprise an economically significant group of cool season crops grown in the coastal production district. Given the configuration, irrigation system, rooting depth and quality demands for these crops, they are arguably the most challenging to efficiently manage for nitrogen. Spinach had the highest total nitrogen (N) uptake of all the crops, followed by mizuna, cilantro and lettuce. Fertilizer N application to N uptake ratios ranged from 1.46 (spinach) to 2.96 (baby lettuce). Mizuna and spinach had the greatest growth rate of the four crops evaluated in this project, averaging 6.5 and 6.7 lbs N /acre/day, respectively, at peak uptake. The percent of the crop biomass N that is harvested with these crops ranges from 60 to 70%, indicating that 30 to 40% of the nitrogen rich residues remain in the field following harvest. Potassium uptake was greater than N uptake for all the crops and varied from 92.6 to 180.6 lbs K/A. Eight fertilizer trials were conducted from 2013 to 2015 evaluating nitrogen technologies (nitrification inhibitors and controlled release fertilizers) for use in high density crop production. A summary evaluation of all eight trials indicated that nitrogen technologies provided little to modest improvements in yield overall. However, in some conditions, they did have an effect, particularly at sites where there was a strong response to N fertilization. Fertilizer technologies may provide a

modest benefit over the long term, but their benefits on an individual field basis may vary widely.

Spinach was added to the on-line decision support program, CropManage. Two evaluations of the use of CropManage to manage the water and N of commercial spinach crops were conducted. CropManage was effective in managing water applications to the spinach. Nitrogen management was also effective, but there were challenges in nitrogen management in commercial field conditions due to rainfall and delays in harvest which necessitated modification of the recommendations made by CropManage.

D. INTRODUCTION

The Central Coast Regional Water Quality Control Board (CCRWQCB) regulations have created the need for N uptake data for a variety of crops. Crops such as baby lettuce, cilantro, spring mix (mizuna, representative spring mix crop) and spinach are grown on 80-inch wide beds that are seeded in 14 to 42 seedlines; they are considered high density plantings because they cover the entire bed top and are exclusively irrigated with sprinklers. Nitrogen uptake and water use of these crops was not well understood. This project evaluated nitrogen uptake and water use by high-density vegetable crops produced in the coastal production district. Understanding the quantity of N taken up by these crops is basic to understanding the efficiency of current fertilizer practices and devising improvements in N use efficiency. In addition, understanding the quantity of water applied during crop production can help to better understand typical water application patterns relative to crop demand (crop ET). The nutrient uptake and water use information developed by this project is being used to develop algorithms in CropManage, an online decision support tool that is designed to assist growers in managing both nitrogen and irrigation management in cool season vegetables.

E. WORK DESCRIPTION

At least 10 biomass and nitrogen uptake evaluations were conducted in commercial production fields from 2013 to 2015 for each of the following crops: mizuna, cilantro, spinach; additionally, six fields of baby lettuce were monitored. Biomass samples were collected from 2 to 4 times during the crop cycle. The number of biomass evaluations depended on how quickly the fields matured and our success in working around the irrigation and spray schedules. At harvest, total N, P and K in the biomass was measured as well at the total N in the harvested portion of the crop and in the residue that remains in the field. Flow meters were installed in four fields of each commodity to measure applied water. Infrared photographs were taken to measure crop growth and development and estimate the crop coefficient for water use evaluations. Total water applied was quantified for each field that was evaluated and compared with crop ET. Information developed by these evaluations was used to develop algorithms in the CropManage for crop development, nitrogen uptake and water use by these crops.

Eight nitrogen technology fertilizer trials were conducted from 2013 to 2015. Trial were conducted in commercial fields with cooperating growers. Soil mineral nitrogen evaluation, plant biomass and biomass N evaluations were completed for each trial which provided the basis for determining crop response to the fertilizer treatments.

Two BMP evaluation were conducted in commercial spinach production fields. Treatments included an area managed with recommendations from CropManage and compared with the grower standard practice. Trials were conducted in the fall of 2015 and the spring of 2016. Soil nitrate levels were monitored by collecting 10 soil cores from the top 12 inches of soil. Each field was set up with two irrigation manifolds so that irrigation applications could be managed separately in the CropManage and grower standard treatments. In the CropManage area, irrigations were applied to the recommendations made by the CropManage on-line support program. Nitrogen applications were also managed by CropManage. In the grower standard area, the grower used his standard irrigation and nutrient management practices. Yield, biomass and nutrient uptake evaluations were made for each treatment.

F. DATA/RESULTS

Nutrient Uptake Evaluations: Spinach and cilantro had the highest overall dry biomass of the four high-density crops (Table 1). Spinach had the highest total N uptake of all the crops, followed by mizuna, cilantro and lettuce. The average N uptake by baby lettuce was 64.7 lbs N/A, however, this is an average of both green and red lettuce types. The mean N uptake by baby green leaf types was 84.1 lbs N/A and for red leaf types, 50.1 lbs N/A. The difference between these two types of lettuce was driven by the biomass production: 27,556 and 13,743 lbs/A for baby green and red lettuces, in 29 days, respectively. Fertilizer N application to N uptake ratios ranged from 1.46 (spinach) to 2.96 (baby lettuce). Mizuna and spinach had the greatest N demand of the four crops evaluated in this project, 6.5 and 6.7 lbs N uptake/acre/day, respectively (Figures 1-4). The percent of the crop biomass N that was harvested ranged from 59.6% for cilantro to 70.5% for spinach; these ratios can vary significantly due to a variety of market and production conditions, but they provide an estimate of nitrogen-rich crop residues that remain in the field after harvest. Cilantro, spinach and mizuna return the greatest quantity of N in the unharvested crop residue. The nitrogen concentration in crop tissue was highest in mizuna and spinach, having with 5.9 and 5.8%, respectively. Phosphorus uptake varied from 5.9 to 14.3 lbs/A in baby lettuce and spinach, respectively (Table 2). Potassium uptake was greater than N uptake for all the crops and varied from 92.6 to 180.6 lbs K/A for baby lettuce and spinach, respectively. Cilantro had the longest average crop cycle (43 days); spinach and baby lettuce were harvested on average at 31 and 29 days, and mizuna at 23 days (Table 2). Days to harvest varied by the time of year, but these data give a relative comparison of the length of the crop cycle of these crops.

Nitrogen Technology Evaluations: A total of eight fertilizer trials were conducted on Spinach from 2013 to 2015. The goal of the trials was to evaluate nitrogen technologies for use in high density crop production. Two types of nitrogen technology materials were evaluated, nitrification inhibitors and controlled release fertilizers. Nitrification inhibitors slow the transformation of ammonium to nitrate by disrupting the action of *Nitrosomonas* and *Nitrobacter* bacteria that carry out this transformation. In so doing, a greater portion of the fertilizer nitrogen stays as the positively charged ammonium molecule which binds to negatively charged clay particles and organic matter. Nitrification inhibitors used in this project included: nitrapyrin (Instinct®), Super U® (dicyandiamide (DCD) + urease inhibitor impregnated on prills of urea), Novatec® (ammonium sulfate treated with dimethlpyrazolphosphate (DMPP)). Controlled release fertilizer used in this project were either polymer coated urea prills or rings of urea molecules (triazone) that release N more slowly. The two materials evaluated were, polymer coated urea (Duration ST® - D45) and triazone (N-Sure), a ring of urea. These materials were compared with ammonium sulfate applied at a standard rate and a moderate rate of N. The moderate rate ranged from 25-35% less than the standard rate and was designed to provide less than maximum yield. All fertilizer technologies were applied at the same rate of N as the moderate rate in order to be able to compare if they provided a boost in yield over the unamended moderate treatment. The goal was to examine the efficacy of these materials for use on spinach which are fast growing crops grown on high-density beds that are sensitive to N deficiency. Tables 3 and 4 summarize 8 trials conducted from 2013 to 2015. In Table 3 the percent yield in comparison with the moderate treatment is shown by trial and as an overall mean. In Table 4 the percent yield is compared with the standard treatment. The data from trial to trial were quite variable and in some trials there was a strong (2013 trial 2), moderate (2013 trial 1), as well as no response to N fertilizer (2014 trial 1) (Table 3). On average, there were no to slight benefits from the N technology materials. Duration 45 had the highest overall increase in yield relative to the moderate treatment and had improved yield in half of the trials. It is interesting to note that trial 2 in 2013 had the most dramatic improvement in yield with D45 and Super U and it was the trial that had the greatest overall N response as seen by the very low yield of the untreated control (32.6%). Table 4 shows the same trends as Table 3, but shows the percent yield of the treatments in relation to the standard treatment. Nitrogen technologies did not provide a simple quick fix to improving nitrogen use efficiency in high density vegetables. However, they did improve the yield of spinach under some circumstances (low N conditions). They may provide a benefit when looked at over the long term, but the effect on an individual crop basis may vary. They do not replace but enhance good basic agronomic practices.

Water Use by High Density Crops: The total volume of water applied to high density leafy green crops was monitored using flow meters and rain gauges. The initial data showed that total water (irrigation water and rainfall) applied to a crop ranged from 2.5 to 10 inches. Although there is insufficient data to make final conclusions, it appears that more water is applied for producing spinach than cilantro (Table 5).

Crop coefficients for high density leafy greens were developed by monitoring canopy development during the crop cycle of commercial fields using an NDVI multispectral camera. Data were fit to the equation based on the canopy model of Gallardo et. al. (1996) for estimating evapotranspiration of lettuce:

$$\text{Canopy cover (\%)} = \text{Gmax}/(1 + \exp(A + B\times\text{day}/\text{Maxday}) \qquad (2)$$

Where *Gmax* is the maximum canopy cover, *A* and *B*are fitted parameters, and *day* is the number of days after planting and *Maxday* is the total days between planting and harvest. Table 6 summarizes the fitted parameters.

Canopy cover is converted to a crop coefficient (Kc) by a modified version of the equation published by Gallardo et al. (1996):

$$Kc = (0.63+1.5\,C - 0.0039C^2)/100 \quad (3)$$

where Kc is the crop coefficient, ranging between 0 and 1.0, and C is percent canopy cover determined in eqn 2. Evaporation from the soil surface is also estimated by the method described by Gallardo et al. (1996) and used to develop the final Kc value used for estimating crop ET.

Rooting Depth: Rooting depth of high density leafy green crops was monitored in commercial fields at weekly intervals (Figs. 5-8). Rooting depth of baby spinach and mizuna reached 18 inches by harvest (30 days), while roots of cilantro reached 30 inches in 46 days.

CropManage Evaluations: Two trials were conducted to evaluate using the web based decision support program, CropManage, to make decisions on irrigation and nitrogen fertilizer application on two commercial spinach plantings. The short crop cycle of spinach makes managing crop decision with CropManage different than other crops that we have worked with because there are fewer irrigation and fertilizations events. For instance, in the fall 2015 trial, after the germination waterings, there were only three irrigations and the time interval between them was long, so we not able to modify irrigation in the CropManage area differently than the grower standard. Fertilizer decisions are tricky with short term crop such as spinach. In the 2015 trial, we did not apply the first fertilizer application because soil test values were 27.4 ppm nitrate-N (Table 7). However, we applied the same amount of N as the grower standard (53.5 lbs N/A) on the second application because soil nitrate-N values were at 10.5 ppm. Harvest of the spinach was delayed by 1 week from the original planned date and the CropManage treatment had less residual soil nitrogen than the grower standard and, as a result, the CropManage treatment yielded 5% less than the grower standard. The irrigation water being used at the site had 0.3 ppm nitrate-N and did not add to the nitrogen budget of the field.

The second evaluation was carried out in the spring of 2016 and is an example of a worst case scenario with regards to nitrogen and water management. The trial was planted on March 4 and 3.1 inches of rain fell in the 10 following seeding. Knowing that big rain events were going to occur following seeding we decided to apply a slow release fertilizer in both the CropManage and standard treatments. 78 lbs of N/A as Agroform® were applied, however, this material turned out to release N too slowly for the crop to effectively utilize. Given the high amounts of rain fall at the beginning of this trial, soil nitrate levels fell to low levels following the March 23 sampling date and never came back up the remainder of the crop cycle (Table 8). The spinach crop was being grown for bunch spinach and was allowed to grow for a longer period of time for the spinach to size up. In the end, 322 lbs of N/A was applied to the crop in both treatments. More water was applied to the CropManage treatment than the grower standard, 7.9 inches vs 6.3 acre inches, respectively. The CropManage treatment yield was 3.7% less than the grower standard, but due to high variability in the field, these differences are not significant.

Table 1. Yield and nitrogen uptake evaluations of cilantro (n=10), baby lettuce (n=11), mizuna (n=10) and spinach (n=10)

Crop	Dry Biomass Lbs/A	Solids %	N content %	N total uptake lbs/A	% N in harvested product	% N in crop residue	N fertilizer lbs/A	N applied/ uptake ratio
Cilantro	1,877.5	10.8	5.1	96.2	59.6	40.4	208.0	2.16
Baby lettuce	1,213.9	6.3	5.3	64.7*	68.0	32.0	191.8	2.96
Mizuna	1,597.1	7.2	5.9	102.7	63.2	36.8	181.3	1.76
Spinach	2,121.6	6.9	5.8	123.5	70.5	29.5	180.5	1.46

* overall mean for baby lettuce, however uptake of N by green and red varies: baby green leaf = 84.1 and baby red leaf = 50.1 lbs N/A

Table 2. Mean days to harvest and phosphorus and potassium uptake evaluations

Crop	Mean days to harvest	P content %	P total uptake lbs/A	K content %	K total uptake lbs/A
Cilantro	43	0.4	6.8	7.4	137.7
Baby lettuce	29	0.5	5.9	7.6	92.6
Mizuna	23	0.6	9.5	5.6	103.1
Spinach	31	0.7	14.3	8.6	180.6

Table 3. Percent yield of fertilizer treatments relative to the moderate fertilizer treatment

Fertilizer Treatments	2013 Trial 1	2013 Trial 2	2013 Trial 3	2014 Trial 1	2014 Trial 2	2014 Trial 3	2015 Trial 1	Overall Mean
Untreated	50.6	32.6	60.9	56.1	95.4	114.8	54.1	66.4
standard	104.6	118.8	116.0	101.0	120.2	110.1	103.9	110.7
D45	---	130.2	82.6	95.3	113.8	113.9	88.8	104.1
Instinct	97.1	100.9	105.5	100.0	---	108.3	85.5	99.6
N-Sure	85.0	80.5	57.8	---	---	---	---	74.4
Novatec	---	---	---	99.4	101.8	112.9	79.9	98.5
Super U	102.5	121.5	74.3	101.0	---	112.0	99.4	101.8

Table 4. Percent yield of fertilizer treatments relative to the standard fertilizer treatment

Fertilizer Treatments	2013 Trial 1	2013 Trial 2	2013 Trial 3	2014 Trial 1	2014 Trial 2	2014 Trial 3	2015 Trial 1	Overall Mean
Untreated	48.0	27.5	52.6	55.8	79.4	104.2	52.2	60.0
Moderate	95.6	84.2	86.2	99.4	83.2	90.7	96.2	90.8
D45	---	109.6	71.3	94.7	94.7	103.3	85.5	93.2
Instinct	92.8	85.0	90.9	99.4	---	98.3	82.2	91.4
N-Sure	81.3	67.8	49.8	---	---	---	---	66.3
Novatec	---	---	---	98.8	84.7	102.5	76.9	90.7
Super U	97.9	102.3	64.1	100.0	---	101.7	95.6	93.6

Table 5. Total water applied to high density leafy green crops.

		Applied Water		
Crop	n	Irrigation	Rain	total
		------ inches -------		
spinach	2	8.06	0.02	8.07
mizuna	1	3.48	0.00	3.48
cilantro	5	4.29	0.70	4.99

Table 6. Parameters of canopy models for high density leafy green crops.

			model coefficients			
Bed width	Crop	Sites	Gmax	A	B	R^2
inches			%			
80	cilantro	4	72.8	6.629	-11.799	0.95
80	mizuna	4	79.5	5.968	-10.379	0.95
80	baby lettuce	4	72.0	6.506	-11.002	0.99
80	baby spinach	10	80.0	5.058	-10.268	0.80

Table 7. CropManage evaluation, Fall 2015: Fertilizer and water applied and biomass and nitrogen uptake.

Treatment	Fertilizer Applied	Water Applied	Biomass evaluation[1] Oct. 20			Commercial Harvest[2] Oct. 28
	lbs N/A	acre inches	Fresh wt lbs/A	Dry wt lbs/A	N uptake lbs/A	lbs/A
Grower Standard	180.3	5.37	17,070.3	1028.1	65.8	8,404.4
CropManage	116.0	5.45	17,270.8	1051.4	64.4	7,986.5
Pr > [t]	---	---	0.8346	0.6037	0.7265	---

1 – Biomass was collected from nearly all above-ground plant material; 2 – commercial harvest clipped the top of the spinach plant.

Table 7 continued. Soil nitrate-N evaluations over the crop cycle; values in parenthesis below each value are the quick test results used to make fertilization decisions.

Treatment	Soil Nitrate-N ppm				
	Sept 23	Sept 29	Oct 5	Oct 12	Oct 20
Grower Standard	41.5	41.3	56.4	37.2	27.5
	(36.8)	(33.2)	(36.8)	(18.4)	---
CropManage	36.9	35.1	37.9	23.7	7.2
	(31.6)	(27.4*)	(28.9)	(10.5**)	---
Pr > [t]	0.6367	0.3081	0.0218	0.0602	0.0036

* based on this value we did not fertilize with 30 gallons CAN17 (64.2 lbs N/A) on October 2; ** based on this value with fertilized with 25 gallons CAN17 (53.5 lbs N/A) on October 12 to carry the crop to harvest.

Table 8. CropManage evaluation, Spring 2016: Fertilizer and water applied and biomass and nitrogen, phosphorus and potassium uptake.

Treatment	Fertilizer applied lbs N/A	Applied water[1] ac inch	Crop ET ac inch	Harvest Biomass April 29 Fresh weight T/A	Dry Biomass lbs/A	N uptake lbs/A	P uptake lbs/A	K uptake lbs/A
Crop Manage	322.3	7.7	6.31	15.06	2999.7	143.1	14.2	191.2
Grower Standard	322.3	7.1	6.31	15.64	3075.2	154.4	15.6	205.1

1 - An addition, 3.33 inches of water fell as rain in both treatments

Table 8 continued. Soil nitrate-N evaluations over the crop cycle

Treatment	Feb 26	Mar 16	Mar 23	Mar 31	Apr 4	Apr 13	Apr 19	Apr 26	May 9
DAGW[2]	-7	12	19	27	31	40	46	53	66
Crop Manage	9.5	18.7	12.9	6.2	7.8	3.0	5.5	0.4	5.9
Grower Standard	11.5	18.9	18.2	6.9	5.8	4.9	5.2	0.8	6.4

2 - Days after germination water

Nitrogen Uptake

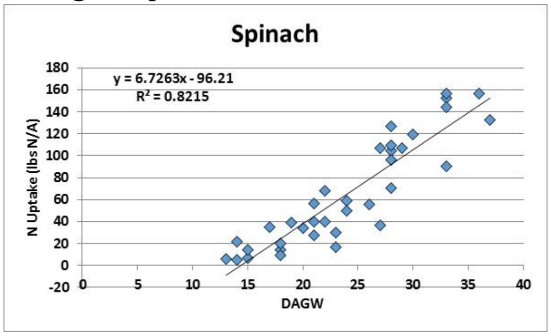

Figure 1. Nitrogen uptake of spinach

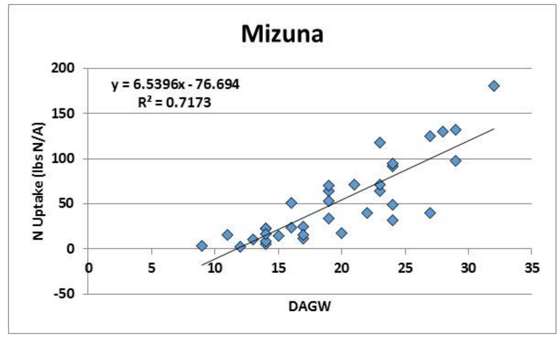

Figure 2 Nitrogen uptake of mizuna

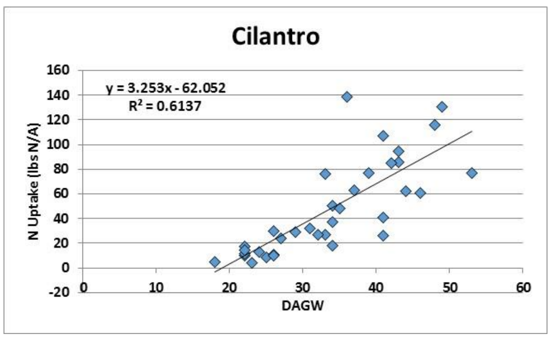

Figure 3 Nitrogen uptake of cilantro

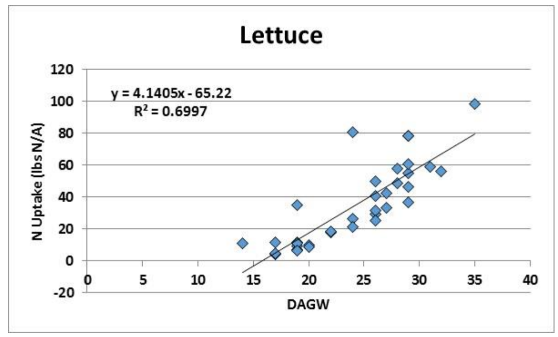

Figure 4. Nitrogen uptake of baby lettuce

Rooting Depth

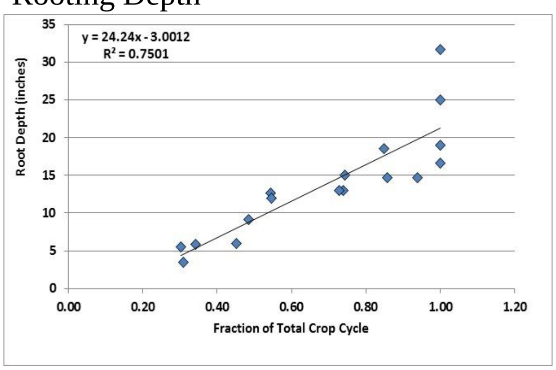

Figure 5. Rooting depth of spinach

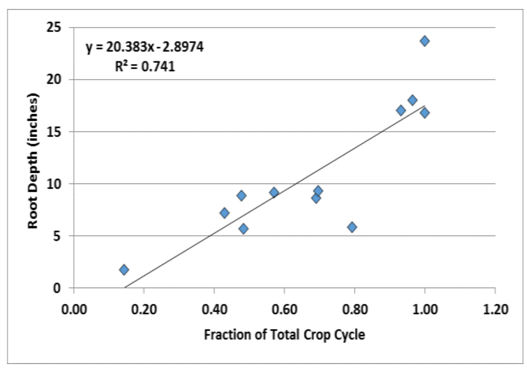

Figure 6. Rooting depth of mizuna

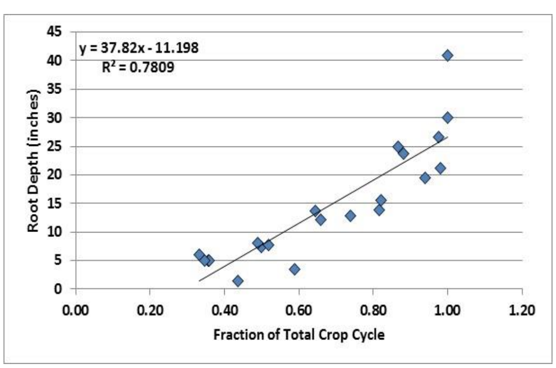

Figure 7. Rooting depth of cilantro

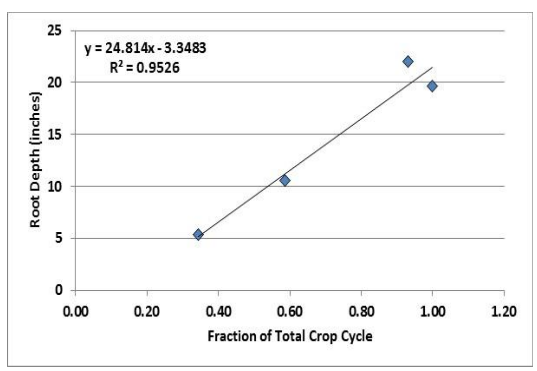

Figure 8. Rooting depth of baby lettuce

G. DISCUSSION AND CONCLUSIONS

Data from these evaluations indicate that the high-density crops take up moderate amounts of N over a short crop cycle. The crop cycle of these crops vary from 43 days for cilantro to as little as 23 days for mizuna with baby lettuce and spinach in the middle of this range. Rooting depth evaluations showed that spinach and mizuna roots were 18 inches deep at the end of the crop cycle (30 days); cilantro has a crop cycle that is 10-14 days longer and as a result, roots reached to 30 inches deep by the end of the crop cycle. These data provide data on the deepest roots of these crops; however, the depth of highest root density and nitrogen uptake is in the upper third to half of the deepest root. The shallowness of the root system makes maintaining soluble nitrate in the area of the active roots particularly challenging for these crops. The range of N applied to these crops varied from 180 lbs/A for mizuna to 208 for cilantro. The ratio between N applied:N uptake was highest for baby lettuce and lowest for spinach. Given the need of maintaining applied nitrogen in the top 8-12 inches of soil, we decided to evaluate nitrogen technologies as a technique for improving nitrogen use efficiency. Nitrogen technologies provided modest improvements in nitrogen use efficiency in spinach in situations with low residual soil N. In general, nitrogen technologies may provide improvements in nitrogen use efficiency over the long term, but the effect on an individual crop basis may vary.

We evaluated crop canopy with NDVI multispectral camera at regular intervals during the crop cycle to develop a time course of canopy development. With this information we developed curves that allow us to know the crop coefficient at any point during the crop cycle. This information is used to develop the crop ET model used by CropManage. The algorithms for modeling water use by spinach in CropManage have been developed. We evaluated them in two trials comparing CropManage and grower standard practices in commercial spinach production. CropManage was effective in managing water applications to the spinach. Nitrogen management was also effective, but there were challenges in nitrogen management in commercial field conditions due to rainfall, delays in harvest which necessitated modification of the recommendations made by CropManage.

H. PROJECT IMPACTS

This project was the first comprehensive look at nitrogen management on high density crops. Crops grown under this production system have significant challenges for improving nitrogen use efficiency. This project shed light on how shallow the rooting system of these crops are and how important good water management is to keeping soluble nitrate in the root zone. We showed that nitrogen technologies will probably only have a limited role in improving nitrogen use efficiency on these crops. This project provided all the data necessary to develop the algorithms to include spinach in the list of crops covered by CropManage. The other crops studied in this project will be added shortly.

I. OUTREACH ACTIVITIES SUMMARY

The educational activities for this project have included all the cool season production districts in California: Oxnard Plain, Santa Maria Valley to the Salinas Valley. Grower have had opportunities to hear about this project at a variety of meetings. CropManage now includes spinach and soon will include other high density crops.

Date	Meeting	Location	Topic	Speaker	Attendance
8/21/13	CAPCA Nutrient Management Meeting	Salinas	Nutrient management update for vegetables	Richard Smith	90
9/17/13	Annual Santa Maria Vegetable Meeting	Santa Maria	Update on nutrient management studies for cool season vegetables	Richard Smith	35
10/3/13	Taylor Farms/Hartnell College Field Crop Supervisors Meeting	Salinas	Overview of fertilization of cool season vegetables	Richard Smith	35
8/21/13	CCA Nutrient Management Seminar	Salinas	CropManage Computer Program	Michael Cahn	
9/17/13	Annual Santa Maria Vegetable Meeting	Santa Maria	CropManage: an online decision support tool for efficient irrigation and nitrogen management of vegetables	Michael Cahn	
3/6/14	Nitrogen and Irrigation Management Class for CCA's	Salinas	Fate and requirements of nitrogen in cool season vegetables	Richard Smith	101
4/8/14	Vegetable production meeting in Ventura County	Camarillo	Nitrogen management in leafy vegetable crops	Richard Smith	28
5/5/14	Agricultural Expert Panel Public Meeting	San Luis Obispo	Report on research on nitrogen use efficiency in cool season vegetables	Richard Smith	40
2/19/15	2015 Irrigation and Nutrient Management Meeting	Salinas	Nitrogen dynamics in high density vegetable production	Richard Smith	105
2/25/15	California crop advisor nutrient training meeting	San Luis Obispo	Irrigation practices for using nutrients efficiently	Michael Cahn	35
4/21/15	Hartnell Community College plant nutrition class	Salinas	Plant nutrition of cool season vegetables	Richard Smith	32
7/30/15	Irrigation and nutrient management meeting for vegetable and berry crops	Oxnard	Nitrogen management of cool season vegetables and N fertilizer technology	Richard Smith	50
7/30/15	Irrigation and nutrient management meeting for vegetable and berry crops	Oxnard	Irrigation strategies for efficient use of nutrients	Michael Cahn	50
8/26/15	CalFERT training	Sacramento	Irrigation practices for leafy vegetables	Michael Cahn	35
2/11/16	San Benito County Water District Growers Workshop	Hollister	Nitrogen use by vegetables and nitrogen technology for addressing water quality issues	Richard Smith	36
2/11/16	San Benito County Water District Growers Workshop	Hollister	Irrigation for efficient use of nutrients by vegetables	Michael Cahn	36
3/28/16	Central Coast Groundwater Coalition	Santa Maria	Nitrogen Management of Vegetables	Richard Smith	31
3/28/16	Central Coast Groundwater Coalition	Santa Maria	Irrigation strategies for efficiently using nutrients in vegetables	Michael Cahn	31
3/31/16	Central Coast Groundwater Coalition	Prunedale	Nitrogen Management of Cool Season Vegetables	Richard Smith	23
3/31/16	Central Coast Groundwater Coalition	Prunedale	Irrigation strategies for efficiently using nutrients in vegetables	Michael Cahn	23
4/20/16	International Plant Nutrition Institute	Gonzales	Nitrogen management challenges of intensive vegetable production systems	Richard Smith	45

Articles:

- Smith, R.F. 2016. Nitrogen fertilizer technologies to improve nitrogen management for leafy vegetable production. CAPCA Advisor XIX, No. 1.

J. Fact Sheet/Data Base Template

1. Evaluation of N Uptake and Water Use of Leafy Greens Grown in High-Density 80-inch Bed Plantings and Demonstration of Best Management Practices
2. 12-0362-SA
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6. Monterey, Santa Cruz and San Benito Counties
7. Highlights:
   - Crops grown in high density configurations on 80-inch wide beds such as spinach, baby lettuce, spring mix and cilantro present particular challenges for nitrogen management because of short production cycles, rapid growth, shallow rooting, sprinkler irrigation and high quality demands for the harvested product
   - Fertilizer technologies were shown to provide a modest improvement in nitrogen use efficiency on these crops in situations with low nitrogen
   - CropManage, the web-based program that provides decision support to growers for irrigation and nitrogen management. Spinach has now been added to the list of crops covered by this program. Basic data for the other high density crops has been collected and they will soon be added to the list of crops covered by CropManage
8. Introduction

This project was undertaken to better understand the nitrogen uptake dynamics of crops grown on high density beds such as spinach, baby lettuce, spring mix and cilantro. These crops present particular challenges to nitrogen management due to their short production cycles, rapid growth, shallow rooting, use of sprinkler irrigation and high quality demands for the harvested product. Through this project we documented their rooting depth, biomass accumulation, nitrogen uptake and water use during the crop cycle. This data was used to develop algorithms in the CropManage, on-line support program in order to add these crops to the list of crops covered by this program. Evaluations of nitrogen technology materials such as controlled release fertilizers (plastic coated urea prills) and nitrification inhibitors were evaluated as a technique to improve nitrogen use efficiency in these high density crops.

9. Methods/Management

A survey of 10 fields each of spinach, baby lettuce, mizuna (a representative spring mix crop) and cilantro were conducted from 2013 to 2015. Crop biomass accumulation and nitrogen uptake were evaluated in each field. A subset of 4 fields of each crop type were outfitted with a flow meters to measure the quantity of water applied from crop establishment to harvest. The flow meters were connected to data loggers to record the length and frequency of irrigations. Infra-red canopy photos were taken every 2 weeks to develop crop coefficients for estimating crop ET. Soil moisture sensors were installed to monitor changes in soil moisture storage. This data provided an estimate the volume of drainage below the root zone.

Eight fertilizer trials were conducted with spinach and baby lettuce to evaluate the use of nitrogen fertilizer technologies: controlled release fertilizers (Duration 45) and nitrification inhibitors (nitrapyrin, DCD and DMPP). Trial were conducted with an untreated control and a standard treatment. A treatment 25-35% less than the standard was included with and without the fertilizer technology treatments to test whether the treatments provided a boost to the yield and improvement in nitrogen use efficiency.

Rooting depth of the crops was measured at weekly intervals during the crop cycle. Evaluation holes were dug at 3 locations in each field of each commodity each year to identify the depth of deepest roots.

10. Findings
Spinach and cilantro had the highest overall biomass accumulation of the four high-density crops. Spinach had the highest total N uptake of all the crops, followed by mizuna, cilantro and lettuce. The average N uptake by baby lettuce was 64.7 lbs N/A, however, this is an average of both green and red lettuce types. The mean N uptake by baby green leaf types was 84.1 lbs N/A and for red leaf types, 50.1 lbs N/A. Fertilizer N application:N uptake ratios ranged from 1.46 (spinach) to 2.96 (baby lettuce). Mizuna and spinach had the greatest N uptake demand of the four crops evaluated in this project, 6.5 and 6.7 lbs N uptake/acre/day, respectively. The percent of the crop biomass N that was harvested ranged from 59.6% for cilantro to 70.5% for spinach.

Nitrogen technologies provided modest improvements in nitrogen use efficiency in spinach. Very low N conditions was the most likely scenario to see improvements with nitrogen technology materials such as plastic coated urea prills. In general, nitrogen technologies may provide improvements in nitrogen use efficiency over the long term, but the effect on an individual crop basis may vary. They do not replace but enhance good basic agronomic practices.

Total water (irrigation water and rainfall) applied to a crop ranged from 2.5 to 10 inches. Crop coefficients for high density leafy greens were developed by monitoring canopy development during the crop cycle of commercial fields using an NDVI multispectral camera. Rooting depth of baby spinach and mizuna reached 18 inches by harvest (30 days), while roots of cilantro reached 30 inches in 46 days.

Evaluations of the use of CropManage to manage irrigation and nutrient application we conducted on two commercial spinach fields. CropManage was effective in managing water applications to the spinach. Nitrogen management was also effective, but there were challenges in nitrogen management in commercial field conditions due to rainfall, delays in harvest which necessitated modification of the recommendations made by CropManage.

K. Copy of the Product/Result

The algorithms developed by this project for crop growth, nitrogen uptake and water use are now in the CropManage web based decision support program and are now available for growers to use to effectively fertilizer and irrigate spinach.

UC ANR 8000 series publications will now be developed to provide technical information to assist growers to fertilizer and irrigate high density crops efficiently.